Chapter 4
Littoral Processes

4-1. Littoral Materials

a. Sources.

(1) The responses of a specific beach depend mainly on the composition and grain sizes of the sediment and on the nature and intensity of the nearshore waves and currents. The sediment may consist of any material that is available in significant quantities and is of a suitable grain size. Most beaches in temperate regions are composed principally of quartz and feldspar grains. These are derived ultimately from the weathering of granitic-type rocks that are abundant on the continents. In addition to the quartz and feldspar ("light minerals"), beach sands generally also contain small amounts of "heavy minerals" such as hornblende, garnet, and magnetite, also derived from the original source rocks. The light versus heavy minerals are defined on the basis of their specific gravities and are listed in Table 4-1. More often they are distinguished in the beach sands by color since the quartz and feldspars are tan, cream, or transparent, whereas the heavy minerals are generally dark (black, red, dark green, etc.). Individual sand grains may consist of more than one mineral type, possibly incorporating both light and heavy minerals. This composite nature becomes more important as the grain size increases, such that most pebbles are small rock fragments.

(2) Shells may represent an important fraction of the beach materials, especially in the tropics where biological productivity is high and chemical weathering of rocks tends to be intense. Shell material may also be abundant because the supply of terrigenous sands is either very low or of the wrong grain size for the particular beach. For example, the shell content of beaches along the southern Atlantic coast of the United States shows a general increase from north to south because of increasing biological productivity and decreasing supply of quartz-feldspar sand to the south. Shells and the derived sands are composed of the minerals calcite or aragonite, whose specific gravities are not much different from quartz and feldspar (Table 4-1). The littoral sediments of volcanic islands commonly consist entirely of fragments of basalt lavas or individual minerals derived from the lavas. Well known are the green-sand and black-sand beaches of Hawaii; the green sands contain a high percentage of the mineral olivine derived from volcanic rocks, and the black-sand beaches consist of fresh microcrystalline lava and volcanic glass.

Table 4-1
Density of Typical Beach Materials

	Specific Gravity (dimensionless)	Color
Light Minerals:		
Quartz	2.65	Colorless, white
Feldspars	2.65-2.76	Colorless, white, light brown
Calcite	2.71	White, yellow, brown, pink
Aragonite	2.93	White, yellow, brown, pink
Heavy Minerals:		
Hornblende	3.0-3.4	Dark green, brown, black
Epidote	3.3-3.6	Green to black
Garnet	3.6-4.3	Red, pink, reddish brown, green
Augite	3.3-3.5	Dark green
Tourmaline	3.0-3.2	Blue, pink, brown, black
Magnetite	5.2	Opaque black
Ilmenite	4.7-4.8	Opaque black

b. Size.

(1) The grain sizes of beach sediments range from large cobbles to fine sand. Terms such as cobbles, pebbles, and sand refer to specific ranges of grain sizes. Figure 4-1 shows the Wentworth Classification where sand encompasses the diameter range 0.0625 to 2 mm, but its category is further subdivided into very fine sand to very coarse sand. The size limits are based on a geometric series involving exponents of 2. For example, the limits for sand are $2^{-4} = 0.0625$ mm and $2^1 = 2$ mm. Geologists use the exponents as a measure of grain size, defining the phi (ϕ) scale as

$$D = 2^{-\phi} \tag{4-1a}$$

or

$$\phi = -\log_2 D = -3.3219 \, \log_{10} D \tag{4-1b}$$

where the grain diameter D is in millimeters. By this scale, the limits of the sand range are ϕ = -1 and 4; note that the higher the value of ϕ, the smaller the grain size so that negative values of ϕ represent the coarsest sizes.

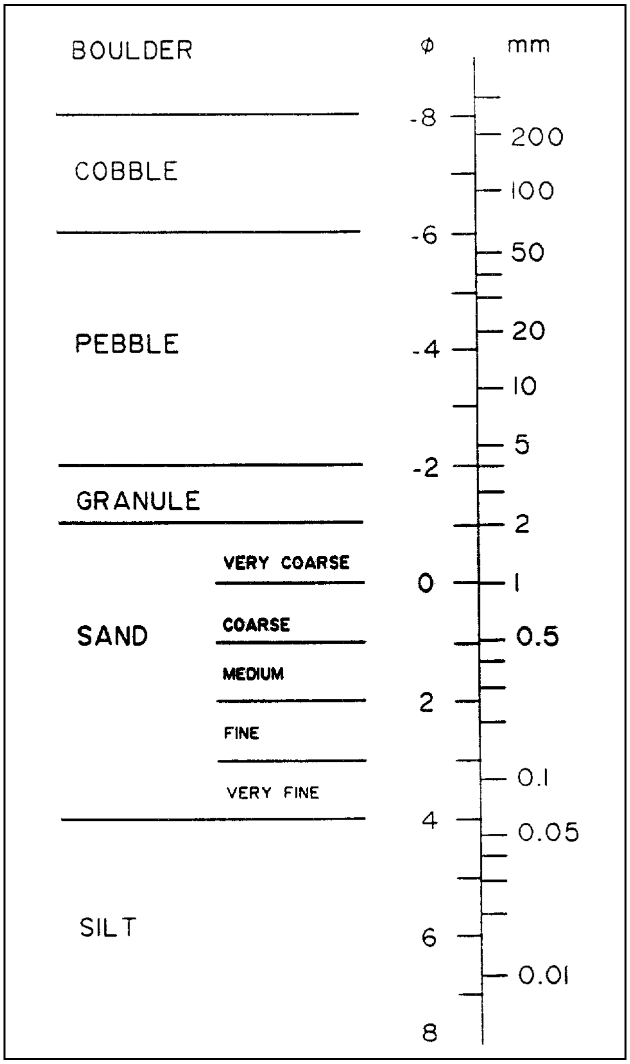


Figure 4-1. Wentworth and ϕ grain size scales

Figure 4-1 gives the limits for the entire list of grain-size terms for the Wentworth Classification.

(2) The term gravel has common usage which roughly corresponds to combined granules, pebbles, and cobbles of the Wentworth Classification, and it will be used in that sense here. Gravel has a more specific designation in the Unified Soils Classification where it denotes sizes between 4.76 mm (-2.25ϕ) and 76 mm (-6.25ϕ) (SPM 1984).

(3) There are three main factors that control grain sizes of sediments found on a particular beach: (a) the source(s) of the sediment, (b) the wave energy level, and (c) the general offshore slope as governed primarily by the geology. The importance of source is obvious. Rocks such as granite tend to weather and break down into their constituent minerals. These form the sand-sized grains of quartz, feldspars, and heavy minerals. These small grains can be transported by rivers for thousands of miles from their original sources prior to being delivered to a beach. Coarser pebbles and cobbles are derived from the physical fragmentation of source rocks and will have the same compositions and densities as the original rocks. Beaches consisting of pebbles and cobbles are generally close to the rock sources.

(4) The beach environment will preferentially select the grain sizes that are appropriate for its particular wave energy level and slope. There is a general tendency for the high-energy beaches (those with the largest waves) to have the coarsest sediments. However, a simple correlation between grain size and energy level for all beaches cannot be made. This is apparent when one recognizes that medium-sand beaches may be found in lakes with very small waves, as well as on high-energy ocean beaches. Headlands often have small pocket beaches of cobbles and boulders, while nearby beaches between headlands are composed of sand. This may be due in part to the higher energy levels on the headland beaches, but also of importance is the general offshore slope upon which the beaches are formed and on the slope of the beach itself.

(5) A sample of beach sediment could contain a distribution of grain sizes that might range, for example, from sand through pebbles. If there is a single mode of sizes within the distribution, then the overall distribution can be characterized by statistical parameters such as the median and mean diameters and the standard deviation which describes the degree of sorting of the sediment. Calculations of these statistical parameters are described in the SPM (1984). Many beach sediments are bimodal, consisting of a sand mode and a separate pebble or cobble fraction. In such cases, separate statistical parameters should be determined for the individual modes.

(6) The distribution of grain sizes affects the porosity and permeability of the beach sediments. Porosity relates to the volume fraction of pore spaces between the solid grains and depends more on the distribution of grain sizes and their packing arrangement than on the absolute sizes of the particles. For most beach sands the porosity, n, is approximately n = 0.4. That is, 40 percent of the bulk sediment volume is pore space whereas the remaining 60 percent consists of solid

sediment grains. Permeability depends in part on the porosity, but it is a distinct property of the bulk sediment and also depends on the sediment size. Although the porosities of a gravel beach and a sand beach may be effectively the same, the permeability of the gravel beach will be much greater. Accordingly, the water from the wave runup on a gravel beach will tend to percolate down into the beach face, whereas the percolation into a sand beach is comparatively minor.

4-2. Beach Morphology and Littoral Processes

a. Beach face slope.

(1) The overall slope of the beach face tends to increase with sediment grain size. This dependence is illustrated in Figure 4-2 which relates the slope of the beach face to the median grain size of sediments collected at the midtide level. The slope of the beach face under the action of wave swash is governed by the asymmetry of the intensity of the onshore swash versus the strength of the offshore backwash. Because of the asymmetry of the incident waves, friction, and water percolation into the beach, the return backwash tends to be weaker than the shoreward uprush. This flow asymmetry moves sediment onshore until a slope is built up in which gravity supports the backwash and offshore sediment transport. When the same amount of sediment is transported landward as is moved seaward, the beach-face slope becomes constant and is in a state of dynamic equilibrium. This final slope will depend on the amount of water lost through percolation into the beach. This rate of percolation is governed principally by the grain size of the beach sediments and, as noted above, is much greater for a gravel beach than for a fine sand beach. The result is that the return backwash on a gravel beach is much reduced in strength, and its slope is accordingly much greater than that for beaches composed of fine sand.

(2) Separate trends are seen in Figure 4-2 for high-energy versus low-energy beaches, a division in the data sets between U.S. west and east coast beaches. For a specific grain size, the low-energy beaches have greater beach face slopes than the high-energy beaches. Also included in Figure 4-2 is a series of data points from Halfmoon Bay, California. This bay is partially sheltered by a headland (see Figure 4-3) which produces a gradient of wave energy and beach face sand sizes along the shore. The wave energy is lowest close to the headland and progressively increases as sheltering of the headland is lost. There is a corresponding change in grain sizes, tabulated in Figure 4-3, with the finest sand found close to the headland where the beach has maximum protection from the waves. The sheltered beach has the lowest slope, due to the combined effects of finer grain sizes and the lower wave energy level. As plotted in Figure 4-2, the measurements from Halfmoon Bay are seen to progressively shift from the curve for low-energy beaches to that for high-energy beaches due to the longshore gradient of wave energy.

b. Profile shape. On most coastlines there are seasonal variations in wave energy, and this produces a change in the slope of the beach and in the overall form of profile. This shift is illustrated schematically in Figure 4-4, characterized in terms of a storm profile versus a swell profile. The terms winter profile and summer profile are also commonly used to denote this change, reflecting its seasonality on many coasts. However, the response is to high-energy, irregular storm waves versus low, regular swell waves, and the shifts illustrated in Figure 4-4 can occur irrespective of season. A specific example of profile response to an individual storm is illustrated in Figure 4-5, based on data obtained at the Coastal Engineering Research Center (CERC) Field Research Facility (FRF) at Duck, North Carolina. Four distinct storms occurred at about a weekly interval, causing a bar to move offshore a total of 172 m (564 ft). The first three storms had a negligible effect on the profile above MSL. Only storm 4, which coincided with a high spring tide and generated the highest waves, caused the upper beach to erode and produced a landward displacement of the MSL line on the profile. As illustrated in Figure 4-4, the high wave energies of many storms combine to cut back the beach face and eliminate most or all of the berm, transporting the eroded sand seaward where it is deposited in the form of offshore bars. The return of low regular waves reverses the process, moving the sand shoreward where it accumulates as a new berm. The slope of the high-energy storm profile is less than that of the low-energy swell profile. This change agrees with the data trends established in Figure 4-2, where it is also seen that seasonal measurements from the Fort Ord and "landing barge" beach sites specifically document changes in beach face slopes while maintaining the same median grain size.

c. Beach profile state.

(1) Empirically based equations or criteria have been developed to predict the beach profile state, or more directly, erosion and accretion, in terms of simple environmental parameters such as wave height, wave period, wave steepness, grain size, and sediment fall speed.

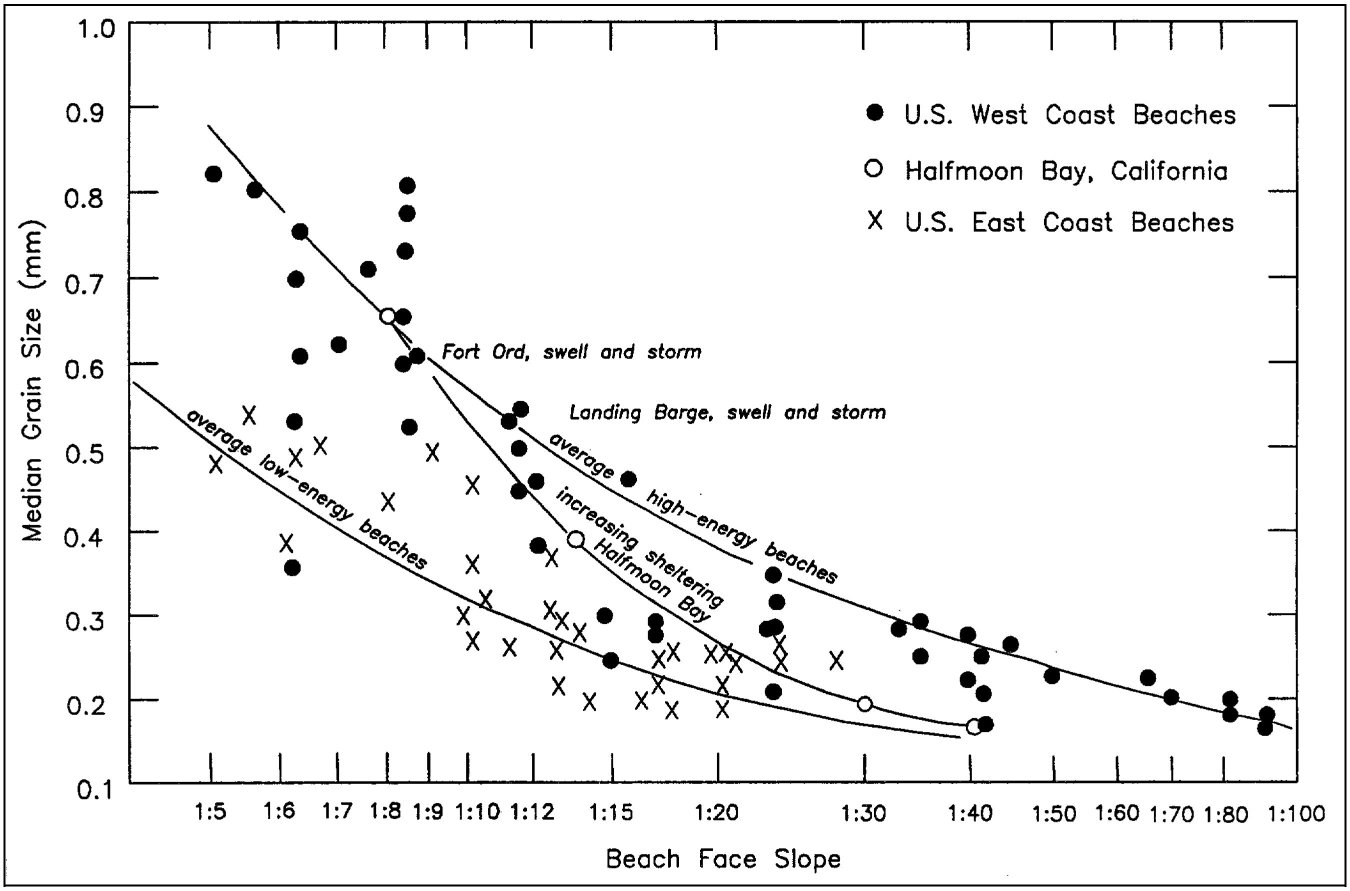


Figure 4-2. Beach face slope dependency on grain size and wave energy

Kriebel, Dally, and Dean (1987), Larson and Kraus (1989), and Kraus, Larson, and Kriebel (1991) have reviewed and compared many of these expressions. An important conclusion from these and similar studies is that experience with profile change in small-scale laboratory experiments cannot be transferred directly to the field situation because of "scale effects," meaning that the absolute sizes of the sand grains and wave height control beach state.

(2) Prediction of beach profile state has practical application to estimate, for example, the stability of natural beaches and beach fills. An important question to be answered is whether beach material of certain grain size will erode or accrete by cross-shore sediment transport under waves of certain characteristics. The subject concerns change in profile state of engineering significance such as that produced by storms and predominant summer and winter wave conditions; the many small changes in the profile that occur hourly and daily are not expected to be predictable without detailed modeling of the many processes involved.

(3) The term "erosion" describes removal of material from the visible beach by wave action, often to produce a gentle slope in the surf zone and one or more large longshore bars in the offshore. The term "accretion" describes sand accumulation in the form of one or more berms on the visible beach and, typically, a steep profile in the surf zone. Although the terms erosion and accretion commonly refer to the response of the visible beach, material is not necessarily lost from or gained by the system but only displaced and rearranged along the beach profile extending from the dune crest to a water depth where no significant net sediment movement occurs. Surveys of wide longshore and cross-shore extent are required to determine if a beach has experienced a net loss or gain of material. Discussion is restricted to beach profile change produced by waves normally or near-normally incident to an open coast.

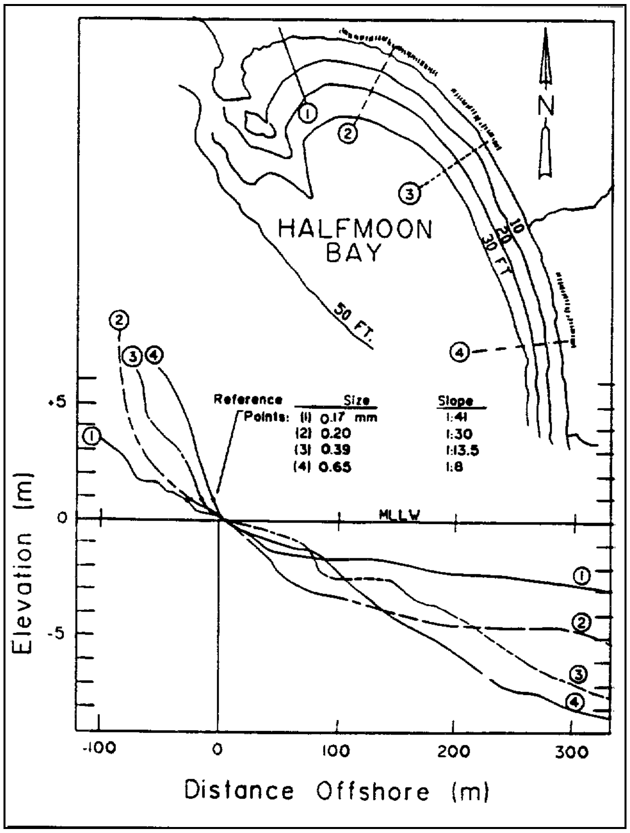


Figure 4-3. Systematic changes in the beach face slope along the length of Halfmoon Bay, California (after Bascom 1951)

(4) Laboratory and field measurements have indicated that the following variables determine in great part whether a beach will erode or accrete: deepwater wave height, H_o; wave period, T; and sediment particle fall speed, w (obtained from knowledge of the median grain diameter d_{50} and water temperature). The three quantities H_o, T, and w can be arranged in several ways in the form of two nondimensional ratios. The two nondimensional ratios used here are

$$\text{deepwater wave steepness} \quad S_o = \frac{H_o}{L_o} \qquad (4\text{-}2a)$$

$$\text{deepwater fall speed parameter } N_o = \frac{H_o}{w\ T} \qquad (4\text{-}2b)$$

in which $L_o = gT^2/2\pi$ is the wavelength in deep water and g is the acceleration due to gravity (g = 9.81 m/sec^2 = 32.2 ft/sec^2). In metric units, $L_o = 1.56\ T^2$ (m) whereas in American Customary units, $L_o = 5.12\ T^2$ (ft), for which T is given in seconds.

(5) For predominantly quartz sand beaches, a sieve-determined median diameter may be an adequate description of grain size. However, the sediment particle fall speed w provides a more general representation of "hydraulic" grain size and can account for the effect

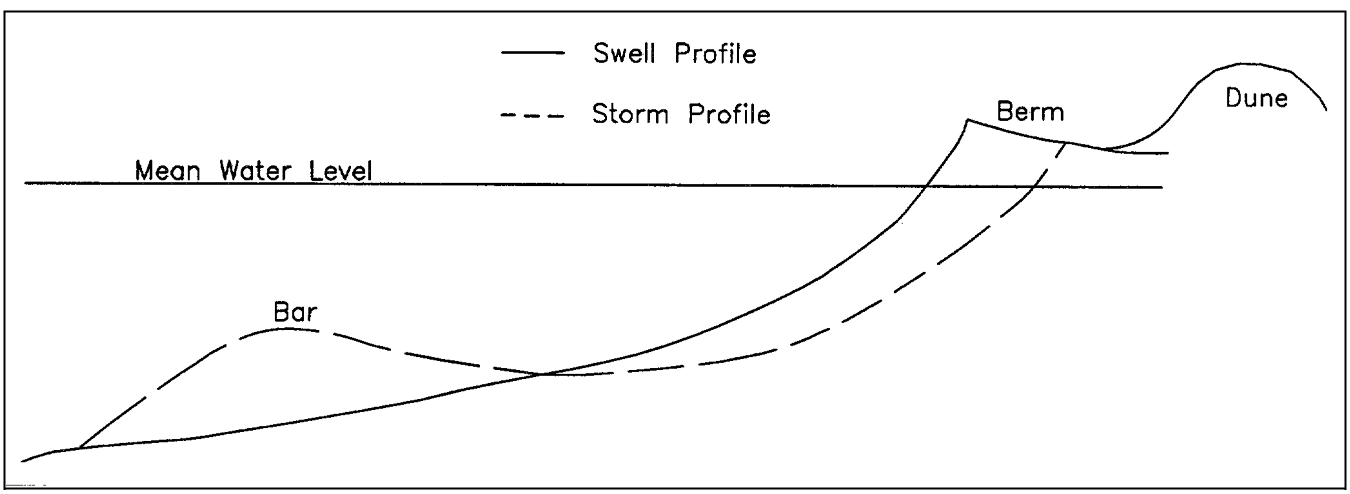


Figure 4-4. Idealized swell and storm beach profiles

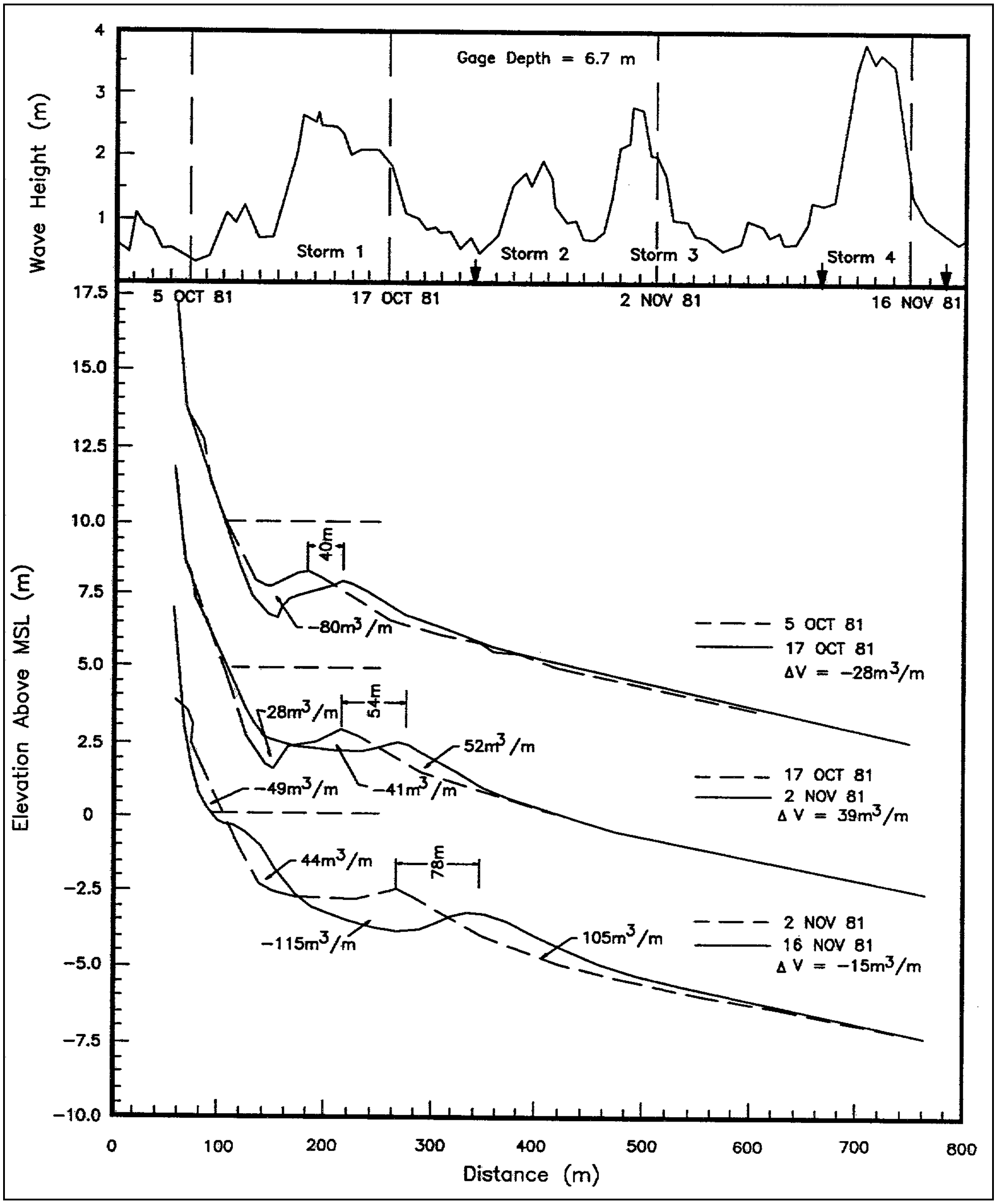


Figure 4-5. Effects of four storms on the beach profile measured near Duck, North Carolina (from SPM 1984)

of water temperature (water viscosity) for which, as an example, lower temperatures would tend to keep sand in suspension. Sand fall speed may be calculated by Equations 4-7 to 4-9 of the SPM (1984). A listing of fall speed values based on those equations is given in Table 4-2.

Table 4-2
Short Table of Fall Speed Values (m/sec) (Quartz Grains)

Water Temperature Deg C	Grain Size, mm 0.15	0.20	0.25	0.30	0.35	0.40
10	0.016	0.023	0.029	0.035	0.042	0.048
15	0.017	0.024	0.030	0.037	0.043	0.050
20	0.018	0.025	0.032	0.039	0.046	0.053
25	0.019	0.026	0.034	0.041	0.049	0.055

(6) Kraus, Larson, and Kriebel (1991) recommend two criteria for predicting erosion and accretion of the beach profile. These criteria were originally evaluated based on two sets of laboratory data (labeled CE and CRIEPI) involving quartz sand, wave and beach dimensions of prototype scale, and monochromatic waves (Larson and Kraus 1989). The criteria were further evaluated using a field data set of 100 erosion and accretion events compiled from the literature describing 31 beaches around the world.

(7) The prototype-scale laboratory tests provide accurate data obtained under controlled conditions and are superior to field observations in that possible factors not necessarily related to the beach sediment and normally incident waves, such as wave direction, lateral boundary conditions, tide and long-period surf beat, are absent. The disadvantage of laboratory tests performed with monochromatic waves is that the appropriate equivalent statistical wave (for example, root-mean-square wave height, mean wave height, significant wave height, etc.) is not known without reference to field data. In comparison of erosion and accretion predictors based on the laboratory and field data, the empirical factors in these criteria retained the same approximate value if the mean wave height was used in the evaluation. Under the standard assumption of a narrow-banded wave spectrum, for which a single dominant peak in wave height is present, the mean wave height $\bar{H}$ is proportional to the significant wave height as $\bar{H} = 0.626 H_s$ (see Table 3-3), and the criteria presented here for field application were modified to allow use of significant wave height. Also, the period associated with the peak in the spectrum should be used in field applications. If knowledge of the spectral peak period is lacking, the period associated with the significant wave height should be used.

(8) *Criterion 1*: This criterion (Larson and Kraus 1989) is expressed as $S_o = M\, N_o^3$, in which the empirical factor $M = 0.00070$ for mean wave height (or for monochromatic-wave laboratory experiments of large scale), and $M = 0.00027$ for significant wave height in field applications. This criterion is shown as the diagonal line drawn ($M = 0.0007$) in Figure 4-6 together with the data from the monochromatic-wave laboratory tank experiments. Wave steepness and fall speed parameter combinations producing a prominent berm (accretion) are labeled with open symbols, and combinations giving a prominent bar (erosion) are labeled with filled symbols. The diagonal line separates regions occupied by erosion and accretion.

(9) Figure 4-7a shows the same criterion (M = 0.00027) plotted against the field data set (using significant wave height), in which open and filled symbols again represent accretionary and erosional events, respectively. The different symbol shapes, denoting beach location, are explained in Figure 4-7b. Although there is some crossing of accretionary and erosional events about the solid diagonal line, the criterion distinguishes the main body of the data for the two beach responses. The dashed lines represent predictions obtained with one-half and double the value of the empirical coefficient and provide a measure of reliability of the prediction. Criterion 1 may be summarized as follows for field applications:

$$
\begin{aligned}
&\textit{If} \quad S_o > 0.00014\, N_o^3 \text{, then ACCRETION is highly probable}\\
&\textit{If} \quad S_o > 0.00027\, N_o^3 \text{, then ACCRETION is probable}\\
&\textit{If} \quad S_o \le 0.00027\, N_o^3 \text{, then EROSION is probable}\\
&\textit{If} \quad S_o < 0.00054\, N_o^3 \text{, then EROSION is highly probable}
\end{aligned}
\tag{4-3}
$$

(10) *Criterion 2*: Observing the trend in the data in Figures 4-6 and 4-7a, a vertical line expressed by the simple equation $N_o = 2.0$ (Figure 4-6, laboratory data, mean wave height) and $N_o = 3.2$ (Figure 4-7a, field data, significant wave height) well separates accretionary and erosional events. By including an error estimate formed by decreasing and increasing the empirical coefficient by 25 percent, the following criterion is obtained for field use:

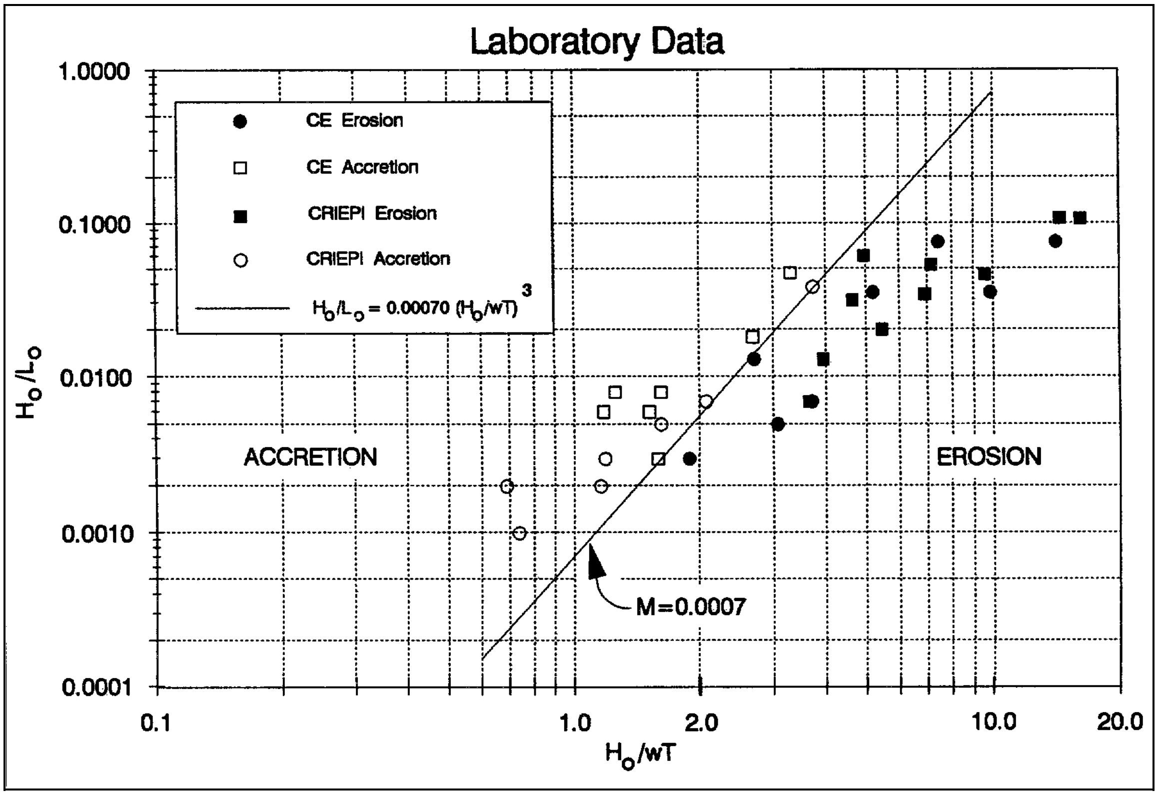
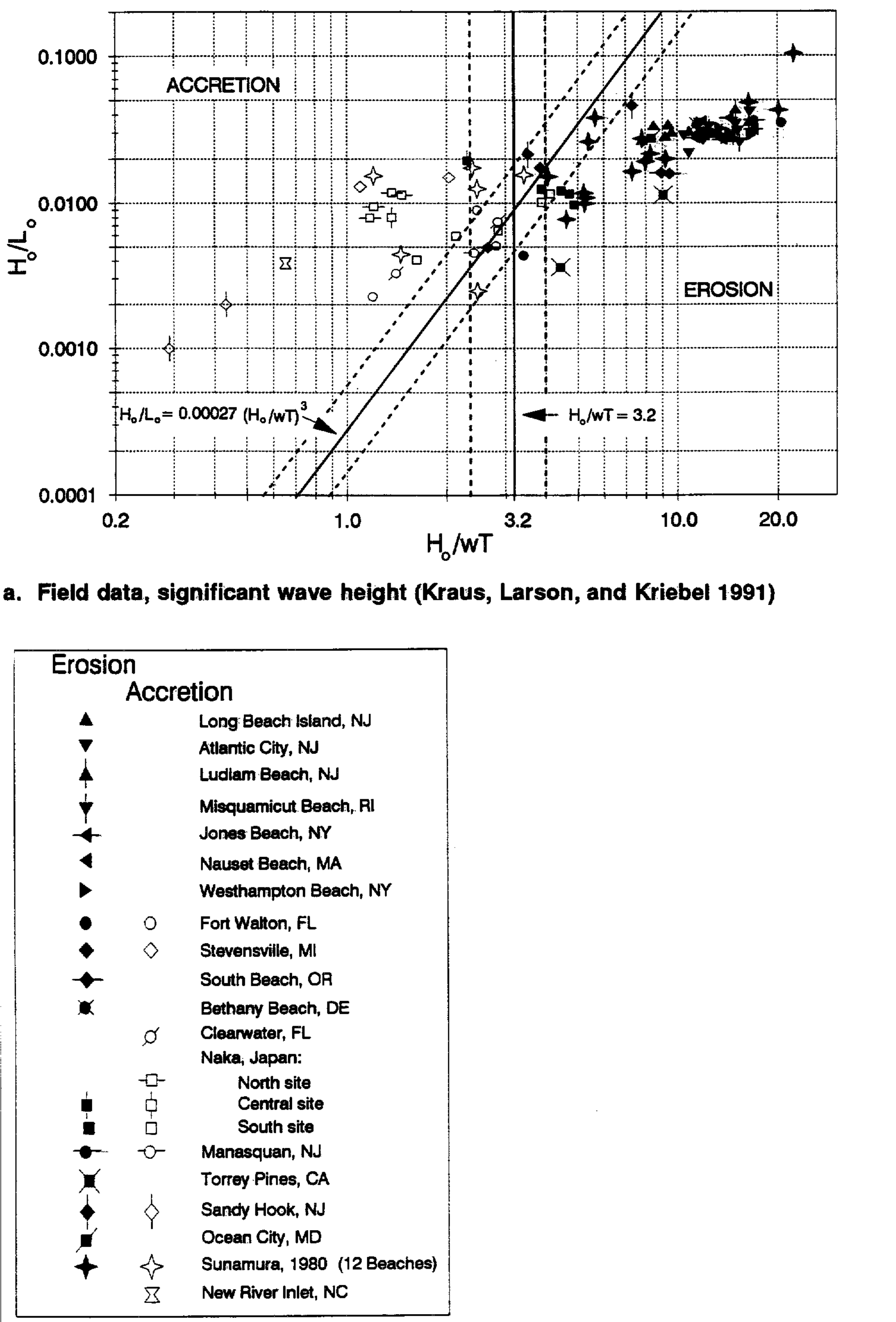


Figure 4-6. Criterion for determining erosion and accretion: large tank data, monochromatic waves (Larson and Kraus 1989)

$$\begin{aligned}
&\text{If } N_o < 2.4 \text{ , then ACCRETION is highly probable}\\
&\text{If } N_o < 3.2 \text{ , then ACCRETION is probable}\\
&\text{If } N_o \geq 3.2 \text{ , then EROSION is probable}\\
&\text{If } N_o > 4.0 \text{ , then EROSION is highly probable}
\end{aligned} \tag{4-4}$$

The parameter N_o was popularized by Dean (1973) in an article devoted to prediction of erosion and accretion and is sometimes called the "Dean number." Wright et al. (1984) used average values of N_o to explain changes in beach state between and including episodes of erosion and accretion. Based on six-and-a-half years of daily observations at three beaches in Australia, Wright et al. found that accretion tended to occur if N_o < 2.3 and erosion if $N_o > 5.4$, in general agreement with Equation 4-4.

(11) The predictive capability of the erosion/accretion criteria can be degraded in three ways. First, the wave height, wave period, and sediment fall speed may be incorrectly estimated. The error bands described above were developed by assuming a 10 percent error in each of these quantities (Kraus, Larson, and Kriebel 1991). Second, factors not directly related to *H*, *T*, and average *w*, such as the tide, surf beat and associated large runup, and variable grain size across the profile, can produce beach change. Third, longshore variability may mask beach change induced by cross-shore transport. Longshore variability includes variations in the incident waves produced by an irregular offshore bathymetry, variations in dune size and composition, three-dimensional circulation patterns containing rip currents, and combined effects of oblique wave incidence and littoral controls such as jetties and groins. The third condition indicates that the criteria are most applicable to straight stretches of beach distant from inlets, jetties, groins, and other coastal structures.



a. Field data, significant wave height (Kraus, Larson, and Kriebel 1991)

b. Beach location symbols for Figure 4-7a

Figure 4-7. Criterion for distinguishing erosion and accretion

(12) It is noted in Figures 4-6 and 4-7a that the two criteria do not cover exactly the same domains, and regions exist in the vicinities of the upper and lower ends of the diagonal line where the criteria will give conflicting results. For example, at the upper end of the diagonal, there are values of wave steepness and fall speed parameter such that Criterion 1 predicts accretion to be highly probable, whereas Criterion 2 predicts erosion highly probable. This region corresponds to steep waves and relatively large grain size (or high fall speed). The available field data do not provide guidance as to which prediction is correct. Because Figure 4-6 indicates a trend that better supports Criterion 1, at present Criterion 1 is recommended over Criterion 2 in situations of conflicting predictions.

(13) A program implementing and automating evaluation of Criteria 1 and 2 is available for use on IBM-compatible personal computers (PCs) (Kraus 1991). The program allows input of wave height and period in deep water or in finite depth water and shoals the wave by linear-wave theory to determine its height in deep water. The sand fall speed is also calculated and output as a function of water temperature and median grain size.

*************** EXAMPLE 4-1 ****************

<u>PROBLEM</u>: Determine, using the criteria presented, whether a beach of specified (quartz) sand grain size will experience erosion or accretion, given a wave condition and two sand sizes. Assume that the water temperature is 20^o C.

<u>GIVEN</u>: **[A]** d_{50} = 0.2 mm, H_o = 1 m, T = 7 sec **[B]** d_{50} = 0.4 mm, H_o = 1 m, T = 7 sec

<u>SOLUTION</u>:

a) Calculate L_o (metric units)

$L_o = 1.56T^2 = 1.56(7)^2 = 76.5$ m; $S_o = H_o/L_o = 1/76.5 = \underline{0.013}$

b) Read w from Table 4-2

[A] $w = \underline{0.025 \text{ m/sec}}$

$N_o = H_o/wT = 1/(0.025*7) = 5.7; \quad N_o^3 = \underline{185.2}$

[B] $w = \underline{0.053 \text{ m/sec}}$

$N_o = H_o/wT = 1/(0.053*7) = 2.7; \quad N_o^3 = \underline{19.7}$

c) Evaluate criteria for each situation

[A]

Criterion 1:

$S_o = \underline{0.013} < 0.00054\ N_o^3 = 0.00054*185.2$

$= 0.10$

indicates <u>erosion highly probable</u>

Criterion 2:

$N_o = 5.7 > 4.0$

indicates <u>erosion highly probable</u>

[B]

Criterion 1:

$S_o = \underline{0.013} > 0.00014\ N_o^3 = 0.00014*19.7$

$= 0.0028$

indicates <u>accretion highly probable</u>

Criterion 2:

$N_o = 2.7 < 3.2$

indicates <u>accretion probable</u>

The two criteria have shown that the finer sand size beach will erode and the coarser sand beach will accrete under the given wave condition.

************** END EXAMPLE 4-1 **************

d. Dissipative vs. reflective beaches.

(1) A more comprehensive classification of beaches than storm versus swell profiles describes them in terms of dissipative versus reflective systems (Wright and Short 1983). These two beach states are contrasted in Figure 4-8. In addition to differing in the nature of the beach profiles, dissipative and reflective beaches differ in the type of wave breaking, the importance of surf bores, and in the nature of the nearshore circulation. On dissipative beaches the waves break by spilling and continue as bores across the wide surf zone which has a fairly uniform and gentle slope, with only subtle longshore bars. On a fully reflective beach, waves break by plunging or by surging, and the surf zone is narrow so that breaking is immediately followed by intense wave swash. A pronounced step is generally found at the base of the steep beach face, with the offshore bottom slope being significantly less.

(2) Dissipative beaches typically have spilling breakers which continuously break across the surf zone. For this type of breaking wave, a smoother cross-shore profile for the longshore current and the longshore transport would be observed. Reflective beach profiles dissipate more energy at the breakline; hence, the longshore current and sediment transport would be concentrated in this region. The impact that short cross-shore structures such as groins have on the littoral system is, therefore, a function of the beach type. A short structure may have a more significant impact on a dissipative profile than a reflective profile.

(3) The storm (erosive) and swell (accretive) profiles of Figure 4-4 may correspond respectively to dissipative and reflective beach systems. Therefore, some beaches will show seasonal shifts from reflective to dissipative, or shifts during individual storms. However, a beach composed of coarse sediments might always be reflective, whereas a fine sand beach is dissipative irrespective of the wave conditions. Wright and Short (1983) have recognized a series of intermediate states which are characterized by the geometry of the offshore bars, longshore rhythmicity, and the importance of rip currents in the nearshore water circulation. A particular beach might pass through all or part of this sequence during and following a major storm. A particular beach may also tend to shift from dissipative toward reflective as the tide level increases. This is due to the concave-up nature of most beach profiles so that the effective slope is steeper at high tide than during low tides, causing a change in surf zone processes indicative of dissipative versus reflective conditions.

(4) Wright and Short (1983) have established that the extremes in the beach state, dissipative versus reflective, depend on a scaling parameter that is equivalent to the Irribarren number or surf similarity parameter, I , where

$$I = \frac{m}{\left(\frac{H_b}{L_o}\right)^{\frac{1}{2}}} \tag{4-5}$$

in which m is the beach slope, H_b is the breaker height, and L_0 is the deep-water wavelength. The beach will be strongly reflective if $1 < I < 2.5$, whereas values for purely dissipative beaches are typically $0.1 < I < 0.3$.

(5) A basic attribute of the dissipative beach system is that effectively all of the arriving wave energy is dissipated in the nearshore. In contrast, on a reflective system a significant portion of the wave energy is reflected back to sea. The wave bores on a dissipative beach continuously lose energy as they cross the wide surf zone and have little energy left when they reach the shore. Measurements of wave runup on dissipative beaches have shown that little energy remains at the periods of the incident waves (Guza and Thornton 1982, Holman and Sallenger 1985). Instead, most of the energy of the runup on the beach face occurs at longer periods, typically on the order of 30 to 120 seconds, termed infragravity motions. It has been observed that dissipative beaches are more conducive to the formation of infragravity edge waves. These low frequency waves concentrate wave energy on the upper beach profile and may be associated with increased erosion and sediment transport. So again, short structures would have a larger impact on dissipative beaches. Figure 4-9 contains data from a dissipative beach in California and shows that as the significant wave height of the incident waves increases, there is not the expected increase in runup

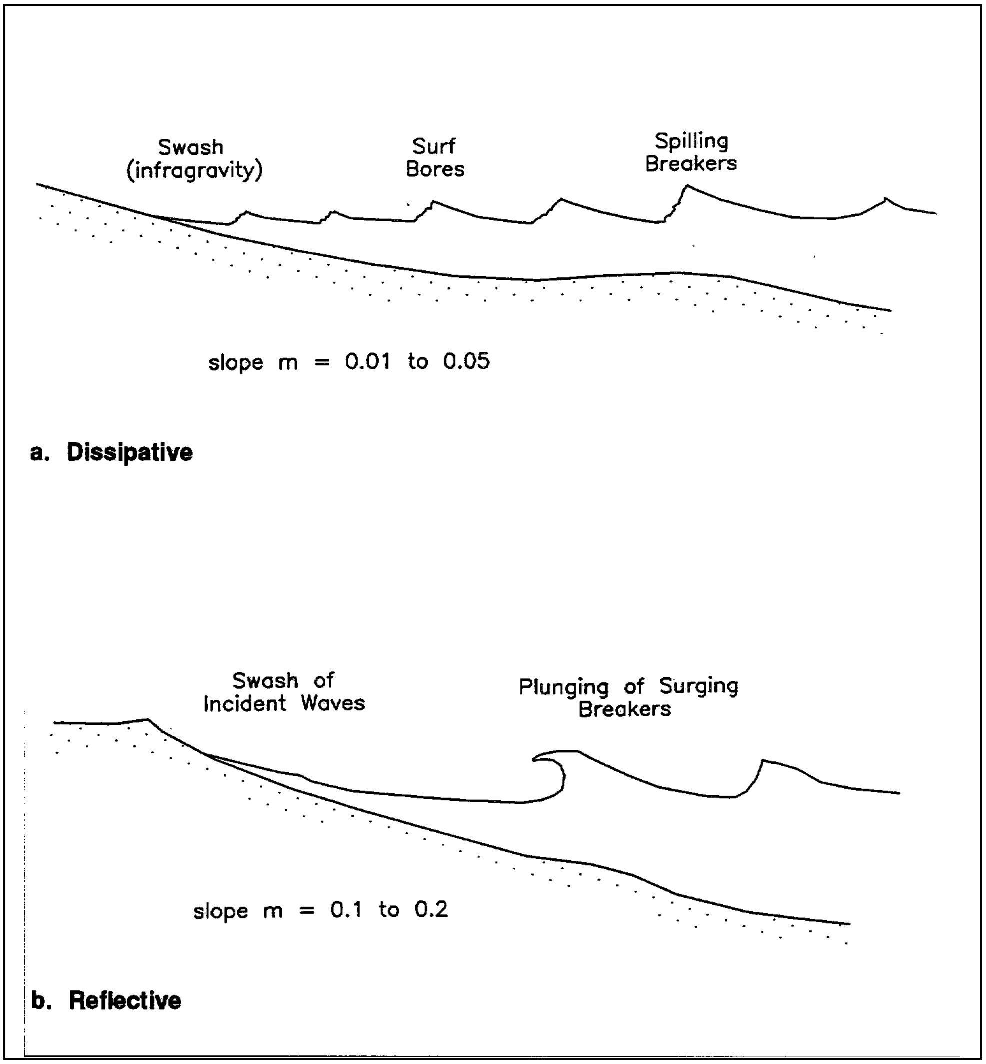


Figure 4-8. Examples of beach states

energy at incident wave periods. This is because, on dissipative beaches, an increase in heights of incoming waves causes them to break farther offshore, producing a greater distance of bore travel and decay so there is little change in runup energy of the bores at the shoreline.

4-3. Littoral Budget

a. Introduction. Beach erosion results if more sand leaves a coastal site than reaches it. This represents a deficit in what is commonly termed the budget of littoral sediments, and is an application of the principle of continuity or conservation of mass to the littoral sediments. In practice, the analysis evaluates the various sediment volume contributions (credits) and losses (debits), and equates these to the net gain or loss for a given sedimentary compartment or stretch of coast. This balance of sediment volumes is reflected in local beach erosion or deposition, depending on whether the balance is in the "red" or "black."

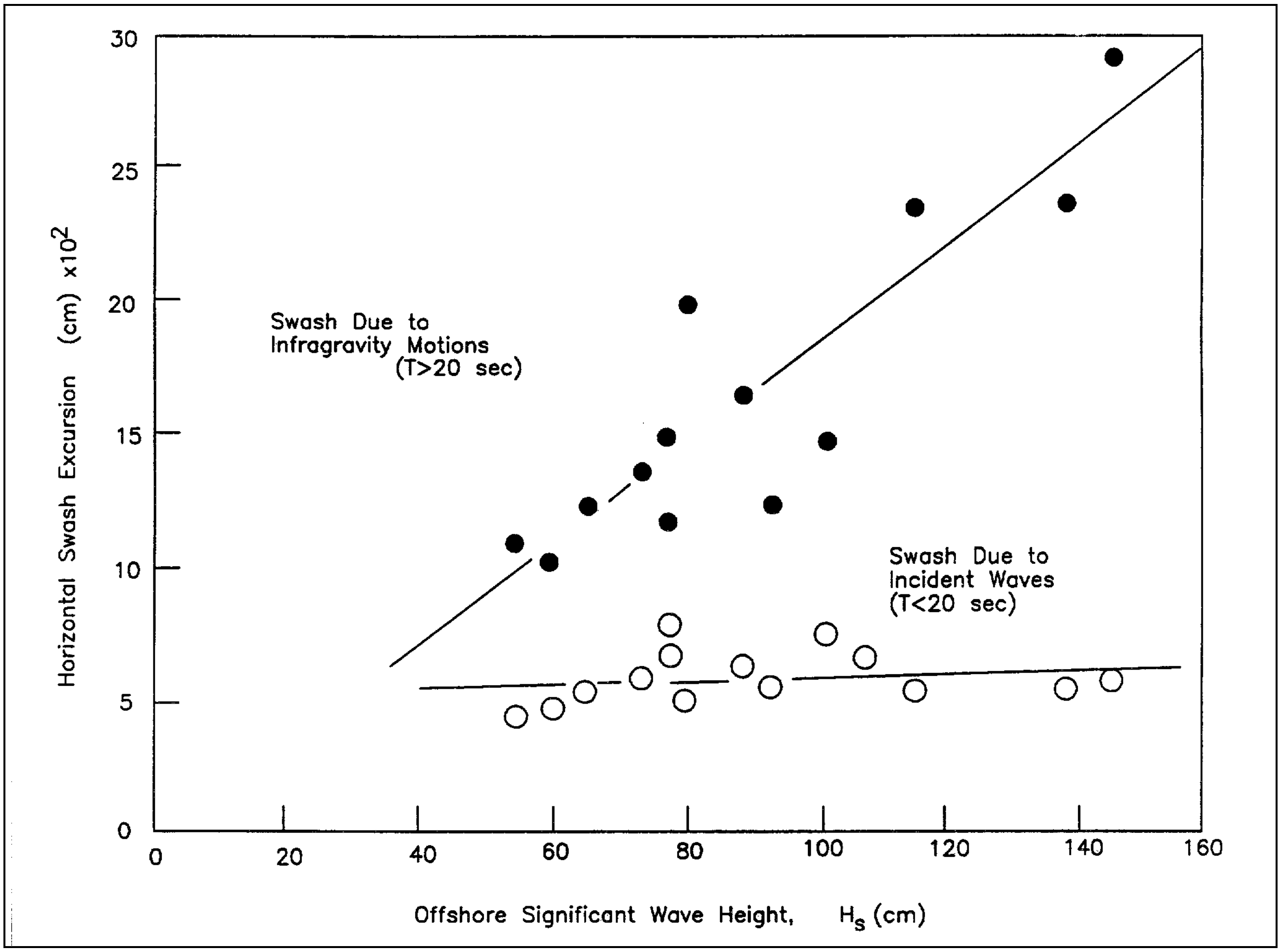


Figure 4-9. Dependency of the horizontal swash excursion on offshore wave height for wind and infragravity frequency bands (Guza and Thornton 1982)

b. Sources and sinks.

(1) There are many potential gains and losses of beach sediments that can play a role in the budget. In general, sand supply from rivers, sea cliff erosion, and longshore sediment transport into the area constitute the major natural sources. Natural losses can include sand blowing inland to form dunes, offshore transport to deeper water, and the longshore transport that carries littoral sediments out of the study area. Beach nourishment represents a human-induced gain in the budget, one that is designed to shift the balance to the surplus, replacing erosion with deposition. Sand mining is a human-induced deficit in the budget. Figure 4-10, summarizes the various possible losses and gains in a littoral budget.

(2) An application of the budget of sediments requires a quantitative evaluation of the various gains and losses. This includes assessments of the annual discharge of sediments from rivers entering the study area, the amount of sand blown inland to form dunes, the littoral drift, and so on. These quantities are then balanced to evaluate the resulting erosion (negative balance) or deposition (positive balance). Detailed discussions of how these gains and losses can be evaluated are given in the SPM (1984), and two examples

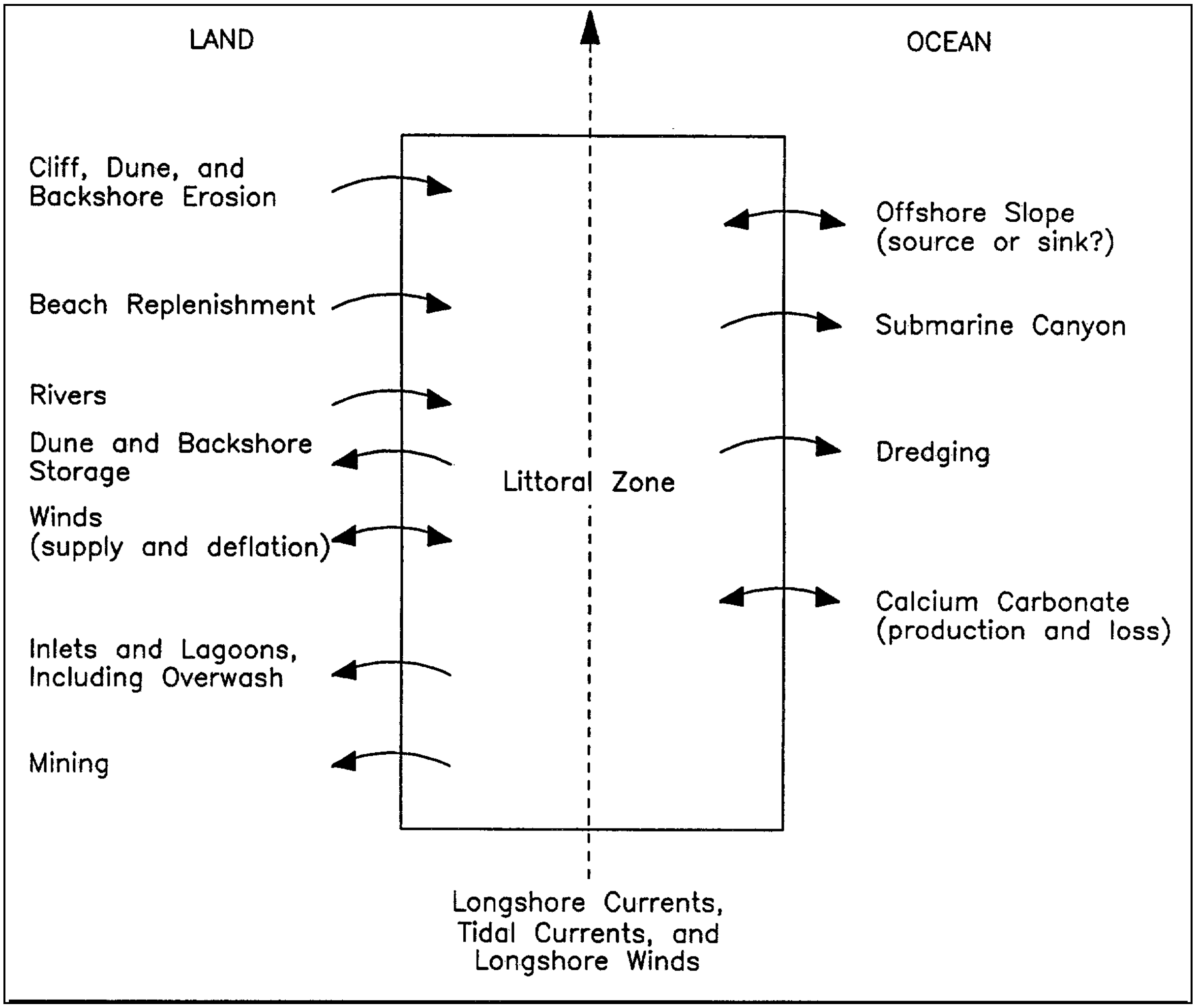


Figure 4-10. Materials budget for the littoral zone (SPM 1984)

are presented in Chapter 7. In practice it is often difficult to make reasonable estimates for some of these quantities. Evaluation of the losses or gains from the offshore is particularly difficult. Generally, the best known component in the budget is the balance itself, the rate of erosion or deposition on the beach. Knowing that balance, it is sometimes possible to work backwards to arrive at reasonable estimates for the multiple inputs and outflows of sand.

c. Littoral cells. In some coastal areas there are natural compartments or littoral cells that help define the stretch of beach to which the budget of sediments is evaluated. Headlands and long jetties are particularly useful in this regard, if they block longshore sediment transport. A good example of this is the coast of southern California which is divided into a series of sedimentation cells (Figure 4-11). In each cell the mechanisms that add and remove sand are balanced. Rivers and cliff erosion are the principal sources of sediments for the beaches in the cells, and the chief losses are the series of submarine canyons which bisect the continental shelf and intercept the sand as it moves southward along the coast. In general, it is best to form a sediment budget

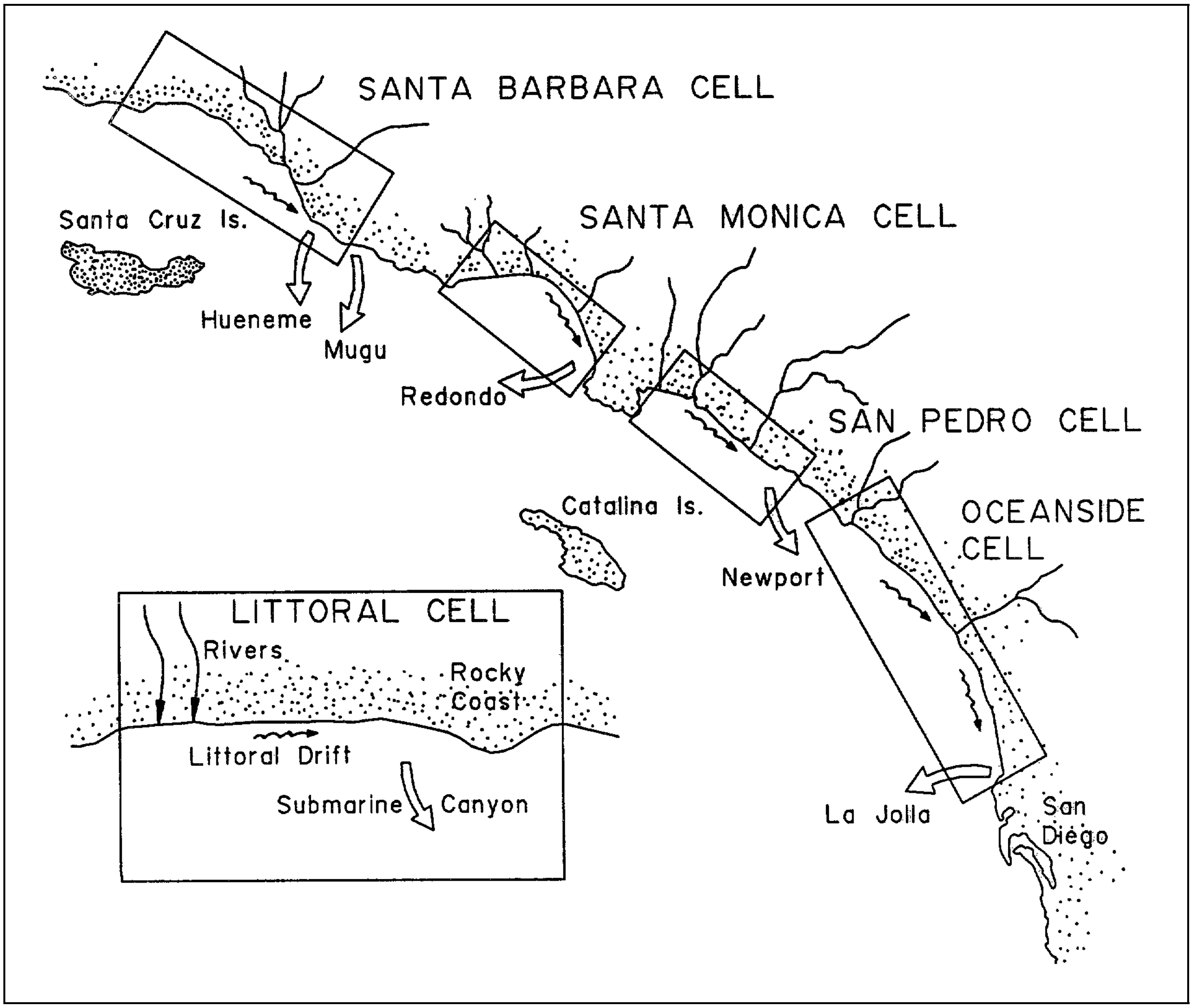


Figure 4-11. Southern California littoral cells (after Inman and Frautschy 1966)

over a region where lateral sediment exchanges can be well estimated, such as regions bounded by headlands, inlets, and jetties.

d. Applications. The budget of littoral sediments is particularly useful in assessing the possible impacts of engineering activities on the coast. For example, once a budget has been developed for the natural conditions at the study site, it is possible to make quantitative evaluations of the effects of a proposed dam on a river that would cut off one of the sources. Similarly, one can assess the impacts of sand mining on the beach, the placement of a protection structure to halt sea cliff retreat (the erosion of which supplies sand to the beach), or the construction of a jetty which interrupts longshore sand movements into the study area.

4-4. Beach Nourishment

a. Beach nourishment involves the placement of substantial quantities of compatible sand to advance the shoreline seaward and is usually undertaken to reverse a trend of beach recession. The wider beach following nourishment is better able to act as a buffer, providing protection to upland structures from storm waves and inundation. Another direct benefit is the recreational value of the enlarged beach. An indirect benefit is in serving as a feeder beach for down-coast locations needing a continuous supply of sand.

b. It is important to establish any beach nourishment project within the overall budget of sediments for the area. Such an understanding will aid in recognizing probable rates of beach fill losses, and lead to a better assessment of the lifetime of the project. Beach nourishment can result in a seaward extension of the shoreline and an unnatural increase in sand relative to the original contours. This leads to profile adjustments and the immediate offshore transport of sand, and also movements in the longshore direction that can carry sand out of the nourished area. Models for these processes have been summarized by Dean (1983) and can be used to predict the fate of the nourished sediments.